WIRELESS GESTURE CONTROLLERS TO AFFECT INFORMATION SONIFICATION

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ABSTRACT

This paper proposes a framework for gestural interaction with information sonification in order to both monitor data aurally and, in addition, to interact with it, transform and even modify the source data in a two-way communication model (Figure 1). Typical data sonification uses automatically generated computational modelling of information, represented in parameters of auditory display, to convey data in an informative representation. It is essentially a one-way data to display process and interpretation by users is usually a passive experience. In contrast, gesture controllers, spatial interaction, gesture recognition hardware and software, are used by musicians and in augmented reality systems to affect, manipulate and perform with sounds. Numerous installation and artistic works arise from motion-generated audio. The framework developed in this paper aims to conflate those technologies into a single environment in which gestural controllers allow interactive participation with the data that is generating the sonification, making use of the parallel between spatial audio and spatial (gestural) interaction. Converging representation and interaction processes bridge a significant gap in current sonification models. A bi-modal generative sonification and visualisation example from the author's sensate laboratory illustrates mappings between socio-spatial human activity and display. The sensor cow project, using wireless gesture controllers fixed to a calf, exemplifies some real time computation and representation issues to convey spatial motion in an easily recognised sonification, suitable for ambient display or intuitive interaction.

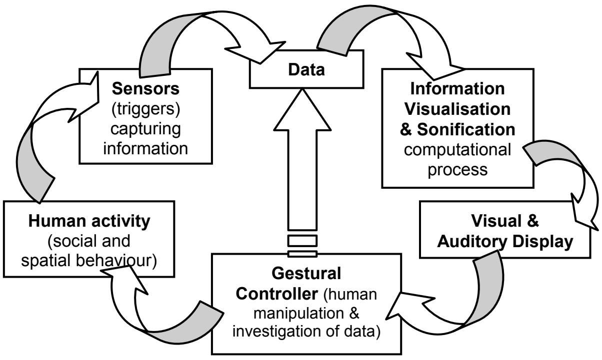

Figure 1. *Knowledge flows from socio-spatial activities to sensors that capture data, through a computational process generating a visualisation/sonification in real time. This loop is completed when gestural controllers are used for spatial interaction to manipulate or investigate this data.*

1. INTRODUCTION

Both information visualisation and information sonification employ a computational process for scaling data, converting it through an algorithmic process of representation, to produce an outcome that is (passively) received by the user. As the objective is to develop a greater rapport with the information, especially socio-spatial data (how people move, relations in spaces, proximity to objects, clustering, eccentric behaviour, velocity and level of traffic), gestural interaction with the information sonification enhances the ability to transform and manipulate the data by interacting with its representation.

This interaction is divided into two categories:

1) gestural interaction with abstract, remotely-located data (stocks, Internet traffic, building lifecycle data, etc.) in which gestural interaction can transform or manipulate the data by altering the original data set;
2) gestural interaction in a sensate space in which the sonification contributes to our understanding of the activity within the space and the information is captured within the space. In this instance, gestural interaction is interactivity that becomes further reflected in the auditory display. There is a distinction between capture devices (sensors) taking in information and modes of interaction (gesture controllers) communicating back into the system.

Because socio-spatial data is directly related to positional or spatial axes, 3D spatialised auditory representation has a direct relation with its source data. This utilises the potential of a 3D interface in 3D physical space. Human gestures and sound operate in three dimensional spaces. Three dimensional interaction without traditional mouse and keyboard interfaces underlie the paradigm of non-tactile, seamlessly integrated, pervasive, immersive computing in which the hardware of computing becomes invisible, developing more intuitive interaction.

Gestural computing aims to move away from desk-bound, restrictive computing environments and to move towards computing that is more integral to the building structure and space itself. Our environment becomes more reactive, "smart" and the boundaries between architecture and computing or between working and mobility are blurred. The technologies configured in the sensor-cow project contribute to several technical links in this model.

2. SOCIAL CONTEXTS FOR RESPONSIVE ENVIRONMENTS

Existing sonification often focuses on interpretation of abstract data such as meteorological, stock market trends, Internet traffic. These sonification are removed from the data source: context, place and occasionally time. In contrast, the following examples and the sensor-cow project focus on **real time** sonification in which the outcome and input are experienced simultaneously and co-locationally. Hence, the sonification is intended to help people understand their **social** and **spatial** activity and interaction (with other people and with space).

Emergent Energy (Figure 2) is an iterative, reflexive system of interaction in which motion, speed, number of users and position in a space (triggering pressure sensitive floor mats) determine the growth of a visual design drawn with a Lindenmayer (L-system) generative algorithm. The design provides both an informative monitor of social and spatial behaviour and invokes users to interact with their space to influence their artistic surrounds. The design artefact is an embedded history of the movements, interactions and number of people who produced it (Figure 3 & Table 1).

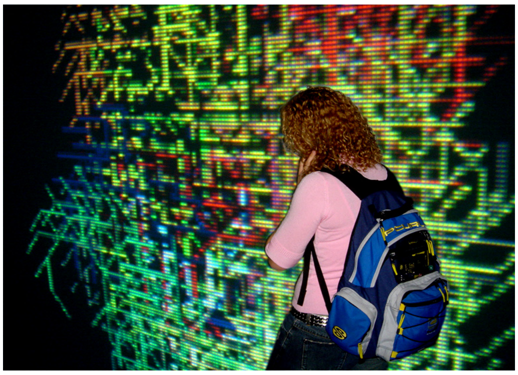

Figure 2. *L-system generator patch in Max/MSP & Jitter used to create branched visualisations on screen. Different behaviours modify the algorithmic process of design generation. Colour of branches indicates spatial location, heaviness of lines corresponds to the number of room occupants and motion affects the rapidity of branching. In the corresponding sonification, the number of people relates to dynamic intensity, position to timbre (tone colour) and speed to frequency (pitch).*

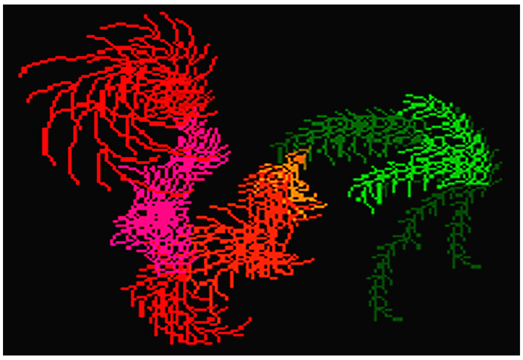

Figure 3. *The Lindenmayer algorithm produces different colours (RGB values) determined by the position of users on pressure sensitive mats and levels of activity affect the branching characteristics. Colour corresponds to different timbres (tone colours) in the sonification and y-axis position determines the pitch (frequency) produced.*

The sensate room configuration is explained in figures 4 and 5 which show the grid of pressure sensitive mats installed underneath the carpet and connection via Making Things Teleo modules [1] to Max/MSP + Jitter [2]. The shortcoming of this arrangement is obviously its site specificity, hence subsequent experimentation using wireless (mobile) sensors (gesture controllers).

Figure 5. *The author's Sensate Lab (2 views) showing the "invisible" pressure sensitive floor mats embedded underneath the carpet, triggering the visual and auditory sound system and (before carpeting) the grid of pressure mats, networked to the Teleo modules.*

Enabling buildings with responsive, "understanding" and feedback capabilities facilitates flexibility and accessibility to assist environmental comfort, navigation for the visually impaired, building awareness, gerontechnology (technologies assisting the elderly), and automated and augmented tasks for the physically disabled. Nanotechnologies - embedding minute sensor technologies in furnishings, surfaces and pre-fabricated building materials - facilitate localised sensate regions and unobtrusive (wireless) distributed networks for data collection. Intelligence and learning capabilities also transform household and commercial products that we use within our everyday spaces (air conditioners, washing machines, coffee machines) contributing to the picture of our increasingly responsive environment.

3. TOWARDS AESTHETIC AND ENGAGING AMBIENT DISPLAY

Scientific sonification or visualisation of abstract data is usually designed for the purpose of illuminating or augmenting our understanding of abstract (non-visual) data. There are contexts in which sonification is more helpful than visualisation: utilising the human auditory capacity for detecting subtle changes and comprehending dense data; and to avoid overload on visual senses, e.g. during surgery, anaesthesiology, and aircraft control. These applications of visualisation and sonification contribute to our understanding of well-known issues, particularly in regard to sonification: "orthogonality [3, 4] (i.e. changes in one variable that may influence the perception of changes in another variable), reaction times in multi-modal presentation [5], appropriate mapping between data and sound features [6], and average user sensibility for subtle musical changes [7].” There is also evidence to suggest that bimodal (visual and auditory) display has synergistic benefits for information representation [8, 9].

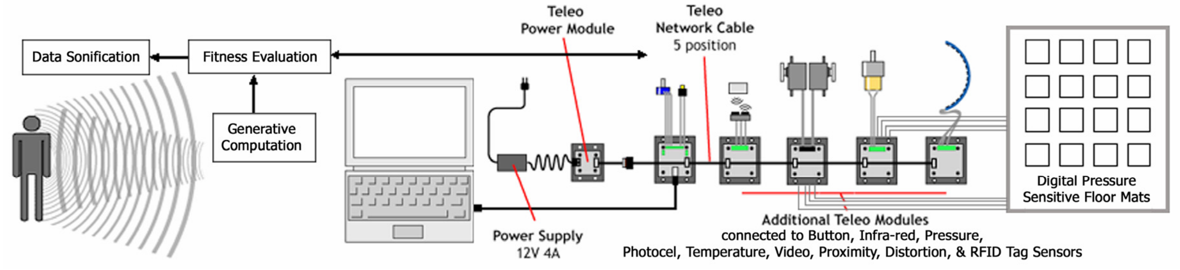

Figure 4. *Configuration of sensate system indicating input from digital pressure sensor mats (and other sensor devices triggered by user interaction – button, infra-red, piezo pressure detection, temperature, light-sensitive photocells, proximity, RFID tags) that provide data for the generative information representation process.*

Table 1. *Sonification schema of mapping correspondences*

Sonification	**Visualisation**	**Activity / Trigger**
Pitch (frequency)	Length/scale/scope of graphic display on screen	Distance between activities / motion
Texture/density	Density of events / number of branches or iterations of generative algorithm (embeds history by amount of activity)	Volume of activity, number of users and social threshold
Rhythm/tempo of events	Proximity and rapidity of display (animation)	Speed of actions, punctuation of triggering events, tied to velocity of events
Intensity/dynamic loudness	Heaviness and distinction of on-screen drawing	Intensity/magnitude of triggering events
Timbre (tone colour)	Colour and distribution on visual display (screen)	Region/spatialisation – topology, zoning
Harmony	Design artefact	Multi-user manipulation

Visualisation and sonification provide useful infotainment for monitoring and display in public spaces, designed to augment, enhance and contribute artistically (as well as informatively) to our experience of spaces, e.g. a foyer, sensate space, common room. Aesthetic representation and accessibility (comprehensibility) directly influences the perception and reception of a work. Granularity or magnification (preprocessing, scaling and density of mapping) also affects our ability to comprehend the representation [10].

Stochastic, algorithmic, generative and deterministic processes applied to musical composition almost always utilise source data predominantly to create “aesthetic” works of art. Rules or grammars of interpretation for transforming algorithmic or non-visual data into auditory parameters are selected to maximise musical effect. Music composers who employ such systematic ways of designing include integral serialists and stochastic composers, Karlheinz Stockhausen, Iannis Xenakis and Pierre Boulez [11]. Ambient sonification concerned with raising awareness of socio-spatial trends in building spaces, in order to be sustainable and listenable over a long period of time, requires an aesthetic approach to pitch representation and other parameters.

It might be argued that sound is even more integrally tied to space than light: “in a natural state, any generated sound cannot exist outside its context” [12] – space is a parameter of sound design, just as is pitch or *timbre*. The following examples (Table 2) illustrate the variety of data that can provide informative and engaging sonification to map abstract, non-visual data to auditory display with a range of scientific and artistic motivations.

Table 2. *Examples of the wide variety of information that can be sonified for variously scientific or artistic purposes.*

Sonification author & title	**Source data**
Ciardi’s *sMAX: A Multi-modal Toolkit for Stock Market Data Sonification* [3]	sonifies data from stock market environments, in which large numbers of changing variables and temporally complex information must be monitored simultaneously
Janata and Childs *MarketBuzz* [13]	sonification of real-time financial data, in which “auditory display is more effective and consistent for monitoring the movement of volatile market indices”
Andrea Polli’s *Atmospherics/Weather Works* [14]	sonified meteorological data designed for museum installation/exhibition with the additional agenda of displaying narrative
Garth Paine’s *PLantA* [15]	using a weather station to capture dynamic non-visual data measurements of wind velocity, direction, temperature and UV levels
Polyrhythm in the Human Brain [16]	derived from EEG brain data

4. AMBIENT DISPLAY AND AMBIENT DEVICES

Ambient visualisation and sonification in buildings merges informative information display with entertainment (infotainment or informative art) bringing a new versatility and purposefulness to graphical and auditory art in our homes and public spaces. This is where the established practice of installation art works concurs with domestic infotainment.

Ambient display devices include plasma, projection, touch screens and audio amplification systems. These output devices can be used for monitoring environmental characteristics – socio-spatial activities. Ambient information representation or pre-attentive display is intentionally peripheral and may doubly serve a role as décor. "Ambient displays normally communicate on the periphery of human perception, requiring minimal attention and cognitive load" [17]. As perceptual bandwidth is minimised, users get the gist of the state of the data source through a quick glance, aural refocus, or *gestalt* background ambience.

In relation to architecture, ambient representation that responds to the building (lighting, airflow, human traffic) as well as to social elements such as human clustering (flocking) patterns, divergences and task-specific data, adds a dimension of responsiveness to the spatial habitat.

5. USING GESTURAL CONTROLLERS AND SPATIAL INTERACTION TO ENGAGE WITH DATA

Introducing gestural controllers as a mechanism for interacting with the 3D spatial auditory and visual representation of information takes this process one step further. There is a chain from building/computer – information – visualisation/sonification – human interaction/manipulation in which tactile, gestural and haptic interfaces provide ways to access and manipulate data and displays without the encumbrance of traditional keyboard/mouse interfaces. The barrier between humans and information, between humans and the smart building are disintegrated while computation and sensing are conflated into a single organism: the intelligent building. Interactive sonification has been used in the past to provide a tangible means for users to negotiate and manipulate the display [18]. This paper proposes a framework in which the interaction can affect and **manipulate the data source** (determining the display), not only its representation.

The science fiction film, Steven Spielberg's *Minority Report* [19] forecasted a kind of interface that is already now achievable: spatial and gestural manipulation of video and computer data on a transparent screen suspended in 3D space (Figure 6). The notion behind gestural information access is an important one: dissolving the hardware and unsightliness of computer interfaces. As computing moves towards people acting in spaces, deviating from our currently sedentary desk-bound lifestyle, the importance of the spatial interaction and experience design, the way in which information is represented, becomes essential. Building architecture and information architecture become one (Figures 1, 7 & 8).

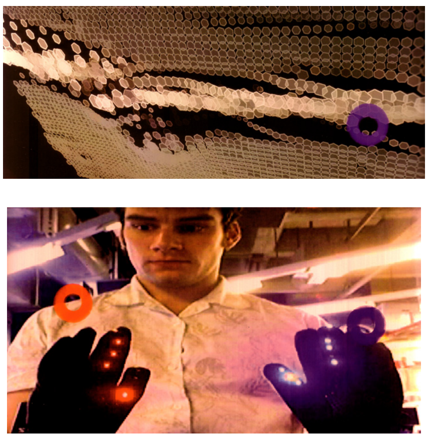

Figure 6. *Justin Manor's Manipulable Cinematic Landscapes [19] is a glove-controlled cinematic landscape interface in 3D space.*

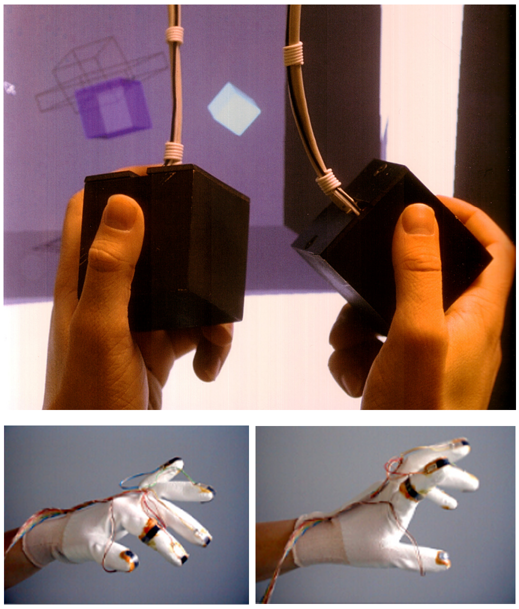

Figure 7. *Haptic (tactile) manipulable cubes in Reed Kram's Three Dimensions to Three Dimensions (top) are creative tools for expression while sensors attached to digits and limbs can be used as gestural controllers for music (bottom) [12, 20, 21].*

Figure 8. *A gestural Cyberglove controller that produces a high degree of accuracy transmitting spatial, position, rotational, gyroscopic, velocity and flex data. The precision facilitates interaction with information representation in 3D space [22].*

5.1. Wireless UDP gesture sensors

In the Sensor-Cow project (Figure 9), the La Kitchen Kroonde Gamma receiver, transmitter and sensor equipment was used (Figure 10). The Kroonde is a wireless sensor interface dedicated to real time applications. Sensors are connected to the wireless transmitter box (worn by the user) which has an effective 914Mhz wireless range of between 100-300 feet, depending on nearby interference (most effective outdoors). The wireless base transmits this information through a high bandwidth Ethernet connection to the host computer with high precision. The Kroonde can also send the data via MIDI. The range of sensors available includes acceleration, gyroscope, motion, pressure, temperature and photosensitivity.

Figure 9. *Sensor-Cow: bi-directional (mercury) motion sensors are attached to the calf's front legs, a gyroscopic sensor on the forehead and accelerometer on his right ear. The pouch hanging around his neck contains the radio frequency transmitter that sends the real time data to the (La Kitchen) Kroonde Gamma wireless UDP receiver [23]. It is connected by Ethernet to the computer running the data sonification with Max/MSP object-oriented programming environment.*

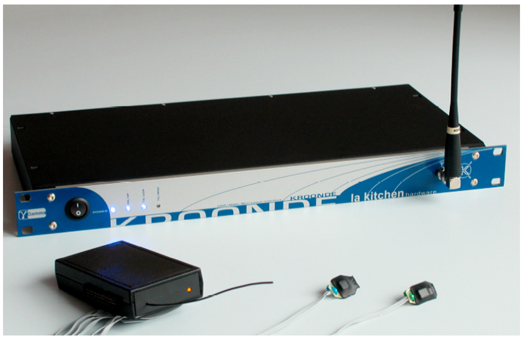

Figure 10. *Kroonde Gamma wireless receiver box, transmitter and attached sensors. The sensors, cabled to the transmitter box, are worn by the user who is then free to move.*

Figure 11 shows the acceleration sensor (at approximately life-size) used for capturing motion data and the UDP transmitter box. Figure 9 shows the way in which these sensors and transmitter are attached to the calf for capturing the data that generates the sonification.

The highly sensitive mercury motion sensors operate between extremes of direction, registering a "bang" (signal to the sonification program) when changes in direction occur. Thus these were attached to the front legs to indicate steps as the calf walks. When calibrated, the gyroscopic and accelerator sensors produce a broad spectrum of values spanning a gamut of 1024 increments mapped to audible pitches. The acceleration sensor values were scaled to 128 distinct output values. These sensors were attached to the calf's ear and forehead, respectively, because these regions isolate significant independent gestures. The calf naturally raises and lowers its head to eat, when flicking away flies, in response to people and other animals - it is expressive and the range of motion is diverse. While naturally following whole head movements, the ear is also flicked and rotated independently producing a recognisable gesture (or musical event).

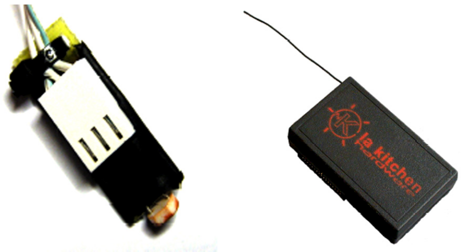

Figure 11**.** *Acceleration sensor and transmitter box.*

5.2. Sonification (mapping) & real-time computation

A distinctive *timbre* (tone colour) is attributed to each sensor in order to make it possible to distinguish the sounds arising from each sensor. The rhythm, pace/acceleration and velocity of action is directly realised in real time. The correspondence between rapid gestures and rapid sonification is literal. For both the acceleration and gyroscopic sensor, extremes of motion away from the median, drives the pitch in directional extremes away from a central pitch region. The direction of pitch, ascending and descending away from the mean, corresponds to the *x*-axis direction of motion so that changes in direction are audible and circular motions of the ear and head produce sweeping auditory gestures that reinforce the audio-visual connection between activity and sonification. The Max/MSP (+Jitter) patch (Figure 12) shows the input reading on the sliders at the top using La Kitchen's Kroonde Gamma patch [24] corresponding to the 4 active sensors, 8 active transmitter channels and potential 16 channel capability of the Kroonde device. The relevant channels are coloured in the diagram, the sonification effects corresponding in colour to the slider input.

This Max patch receives the data via Ethernet connection at a fixed IP address. The hardware is recognised using CNMAT Berkeley's Open Sound Control [25] object. Channels 2-4 (gyroscope and mercury motion sensors) each have an inbuilt threshold within which no sound is produced. Thus stasis produces no constant throughput on these channels. In contrast, channel 1, the acceleration sensor, sonifies a constant data stream, including when the calf is still.

Real-time computation presents several challenges for a modest, portable system because the constant stream of data from the sensors generates massive continuous throughput in the algorithm-to-MIDI chain. When employing a complex elaborative generative system, such as the Lindenmayer evolutionary tree growth triggered by activity on sensor mats (Figures 2 & 3), the system quickly acquires a vast amount of information, at risk of crashing and of saturating the listener. To avoid overloading the output (from a human listener's perspective) and to avoid stifling the algorithmic generative process, the L-system model limited the periodicity of input capture and restricted the pitch continuity of auditory output.

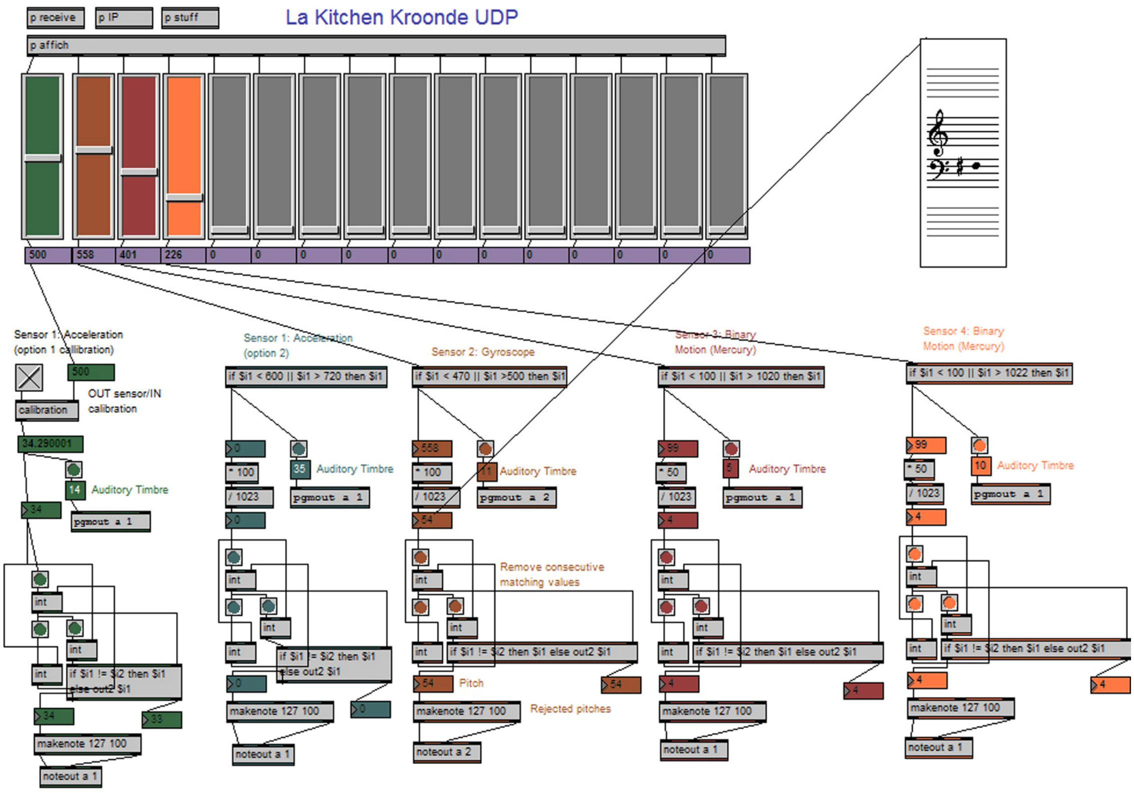

Figure 12. *Max/MSP patch. Data is received wirelessly by the Kroonde Gamma and communicated to the computer by Ethernet. Information is received from its fixed IP address at the top left of the program. The sliders provide a visual monitor of the input signal (the first four channels are active in this project, corresponding to the four sensors) linked to its processing, correspondingly coloured. The information from the first (acceleration) sensor is scaled or calibrated from 1024 increments to 128 output values. An alternative output process for this channel is included but not linked in this example. Channels 2 (gyroscope), 3 and 4 (mercury motion sensors) share a similar sonification process in which superfluous throughput is discarded to reduce the number of pitches heard. Consecutive (repeated) pitches are eliminated and for channels 2, 3 and 4 there is threshold of inactivity that is not sonified so that only more significant gestures are heard. These limitations are imposed to simplify the sonification and facilitate auditory comprehension. Each channel has a distinctive tone colour which can be changed for different effect.*

In the sensor-cow project, the computation is less complex and, in order to make the output both less consuming for the processor and less complex to audit, the broad bandwidth of pitch output was calibrated, scaled and limited to produce pitches separated by small increments rather than producing every available pitch. Gestural motion is still very evident and the result is sufficiently rich to not eliminate any vital data. The sensor-cow patch only uses Max/MSP (the sound processing objects) to produce sonification but if a bi-modal sonification and visualisation is developed using Jitter (processing video objects), a further reduced auditory output would enable faster processing within current equipment limitations.

5.3. Monitoring spatial activity

While the sensor-cow project acts as a monitor of calf motion, and it is unlikely that the calf understands the affects of its actions in contributing to the sonification, socio-spatially generated sonification has the potential in a human context to invoke interaction with the outcome. In a building, people become aware that social group behaviour and different levels of activity influence their experience of the environment. Socio-spatial monitors can tell us about the clustering behaviour of people, trends in motion - paths of flow in a building, peak times of activity, popular junctions and patterns of behaviour related to tasks.

In summary, this paper outlines some ways in which sensate environments and wireless sensors can capture three dimensional spatial and social (behavioural) data to realise a representation of patterns, cliques, clusters and eccentricities in real time responsive environments. Designing the responsive experience with increasingly accessible pre-fabricated sensors and retro-fitted sensate technologies allows building design to flow into the realm of experience and interaction design, dissolving barriers between the computation machine and the visualisation/sonification space. Gestural controllers provide a mechanism for spatial interaction with data representation that absolves the need for visible computing interfaces such as the mouse, keyboard and conventional monitors. Seamless integration of spatial experience and computational response is a direction essential to the future of designing spaces.

The gestural controllers used to activate the sonification of movements in the sensor-cow project provide a working model to pilot test the fine incremental detail transmitted by wireless sensors. The pilot project trials recognisable sonification mapping to represent gestural activity and explores some practical issues associated with spatial freedom, mobility, processing and deciphering signals from a group of distinctive sensors transmitting information about a single individual's behaviour.

5.4. 'The Music Without': Making Music from Motion

'The Music Without' is concerned with exposing the motion of music. Real time computer music responds to sensors placed on the violinist's left-hand finger and forearm and the bowing arm. The gyroscopic, binary-motion and acceleration sensors convey the intensity, physicality and movement (outside forces) that performing involves. Typically, we think of the music within, of the source of musical creation being the mind (composer) and the heart (interpretation). Most reactive, responsive computational real time music systems analyse and respond to pitch, harmony and rhythm. Thus, most systems for improvisation and collaboration are responding to the musician's inner music by "listening" to the auditory outcome.

In contrast, this system creates a response to the forces producing sound, hence 'the music without'. The 'other musician' here is a sonification of the external energies creating music. The system is generating a musical response to physical gestures perceived by the sensor devices. It is not so much listening as feeling, or experiencing the process of performing. This work emphasises a different and often overlooked part of the music-creating process.

The resulting music features audible flourishes associated with large gestures of the performer. Rapid and vigorous activity produces loud and dense bursts of computer music, while specific sensors respond to particular aspects of gestural interaction. A mercury binary sensor is attached on the left-hand middle finger, sending a high-pitched pulse on each change of direction, to convey the rhythmical and persistent infusion of vibrato. Another binary sensor is attached to the bowing arm, close to the fulcrum to capture the beats produced by changing bow direction, again reinforcing the excitement or calmness of the music (Figure 13). The extremely sensitive gyroscopic sensor is attached to the left forearm to capture the significant movements of the position shifts. The acceleration sensor is attached to the bowing arm to convey the almost constant acceleration and deceleration trends and rotations of the right hand. Each sensor's signal is differentiated by *timbre* and register and each has a threshold of inactivity that must be overcome to produce sound.

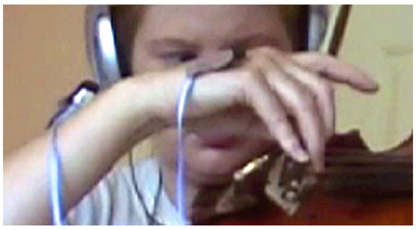

Figure 13. *Sensors are attached to the violinist's left and right hands and arms to capture the physicality of performing: pictures the acceleration sensor and motion direction sensing representing bowing activity.*

5.5. 'Sonic Kung Fu': Colour Sensing Gestural Interaction with Sound

'Sonic Kung Fu' by Jakovich and Beilharz (at *Sydney Esquisse* exhibition, March 2005) is a sonic art installation in which participants wear coloured gloves to perform gestures that produce a real time responsive audio sound-scape (Figure 14). A web cam receives the visual gesture information. The Max/MSP patch responds to the motion of the centre-point of a specific colour (calibrated to match the glove being worn), responding with auditory variation across a range of *x* and *y*-axis values (Figure 15). The immediacy and mapping of this work was intentionally as simple and intuitive as possible for recognition to invoke interaction by passers-by in a gallery setting. The result was that users spent considerable time with the "instrument" learning to understand and control its performance.

Figure 14. *Gestural interaction with auditory display created in response to colour tracking of the spatial glove motion.*

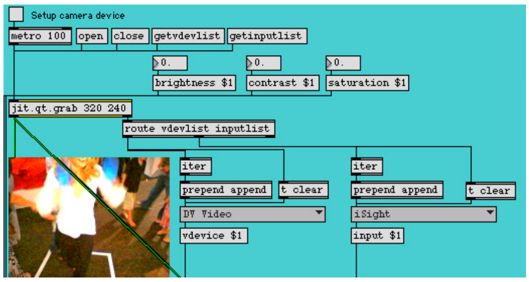

Figure 15. *Max/MSP + Jitter patch tracking colour in the video feed from a webcam and producing auditory display that responds to x- y- position of the glove.*

6. GESTURE AFFECTED COMPUTATION: COMPLETING THE INTERACTION LOOP

Finally, translating gestural interaction in 3D space into **affectors** (software commands) that manipulate the source data demonstrates a complete cycle in which social activities and movement throughout a room produces the sonification that, in turn, can be transformed by the participant. The notion that spatial gesture can affect the source information is applicable in other situations in which the data is abstract and non-social (i.e. not reflexive, iterative) and removed from the context of data capture. **Affectors**, in programming terms, are gestures that trigger a change in information, e.g. motion acceleration thresholds, direction, velocity. The specific affectors are determined by the nature of data sonified and the type of sensors/controllers used. The relations between gestures and affects (transformations) are determined by the sonification designer, in the mapping process. Spatialised audio display (e.g. using IRCAM's multi-channel SPAT) locates sound attributes in 3D space, making it easier to identify, distinguish, then manipulate specific sounds. As sound represents data through the mapping process, moving the sound or interacting with it gesturally is essentially a **reverse-mapping** procedure that alters the data set. Successful gestural interaction with data sonification can be demonstrated by using gesture controllers to change the data set producing the sonification experienced by the participant (Figure 16).

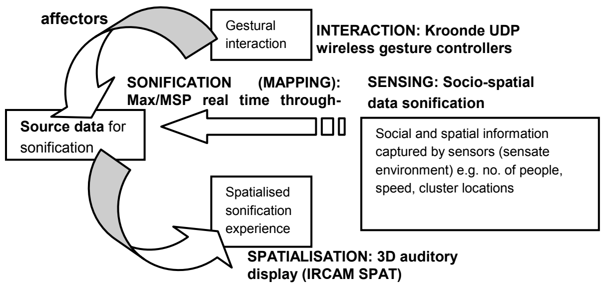

Figure 16. *Gestural interaction using gesture controller devices can be used to affect (change) the source data that produces the information sonification in real time.*

7. CONCLUSION

This paper sets out a framework for linking the use of gesture-controlled audio with traditionally passive information sonification. The bridge provided by affecting **change in a data set** achieved through gestural manipulation of sound completes a loop in the cycle of human-computer interaction. Importantly, the proposed method of transforming data also provides a 3D spatial mode of interaction that is suited to 3D interaction environments, such as Virtual Reality and Augmented Reality. The use of auditory display increases immersion, broadens attentiveness and especially suits information assimilation in already visually-rich environments or those situations where auditory acuity is superior (time-based patterns or low-visibility conditions).

8. REFERENCES

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